Sherpa update: towards NNLO

RadioMonteCarLow2 Working Group Meeting

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UNIVERSITY OF LIVERPOOL

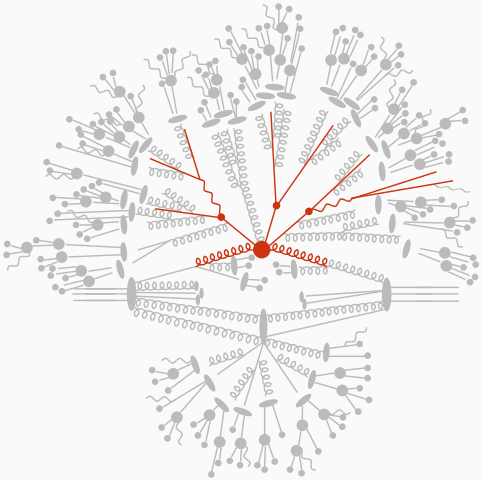
LEVERHULME TRUST

Brief intro to SHERPA

The event generator SHERPA

- General-purpose event generator since c. 2004
- Modules for:
  - Matrix element generation[a]

[a] Tree-level multi-leg inbuilt, loops via interfaces



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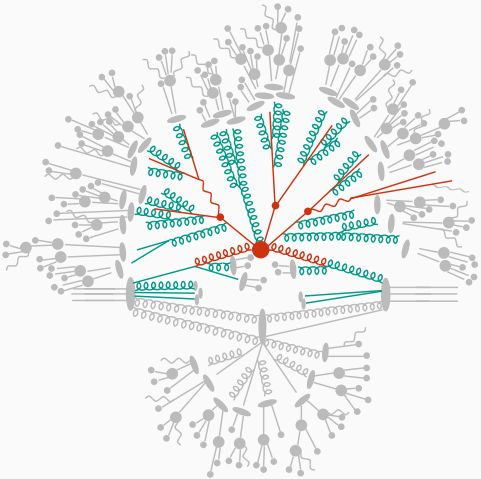

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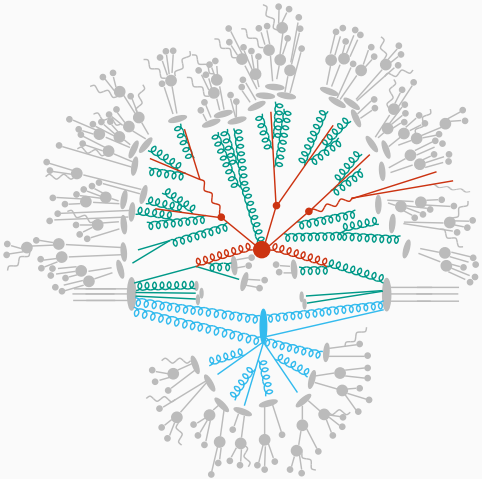

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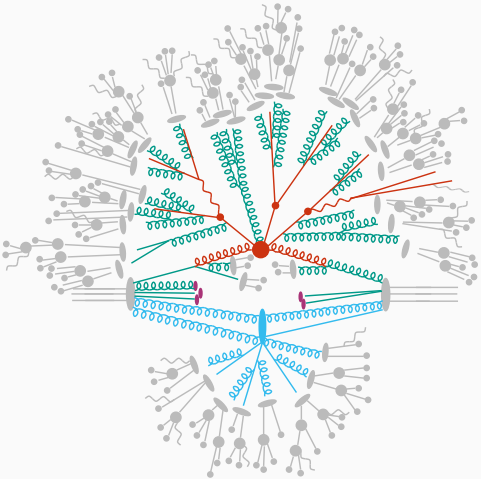

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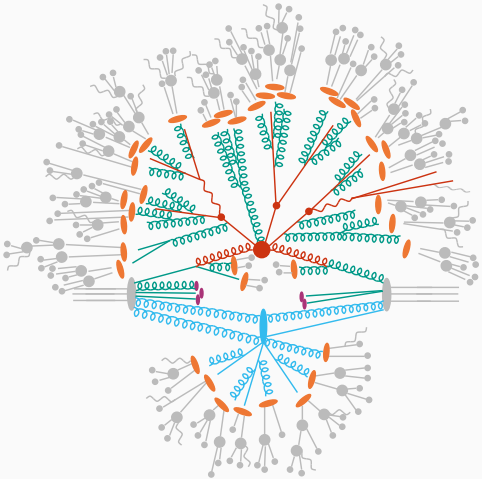

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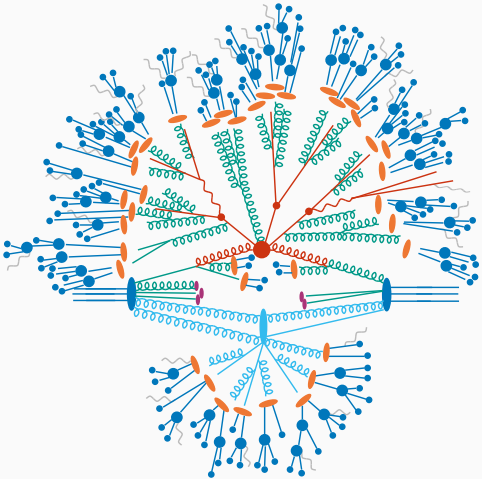

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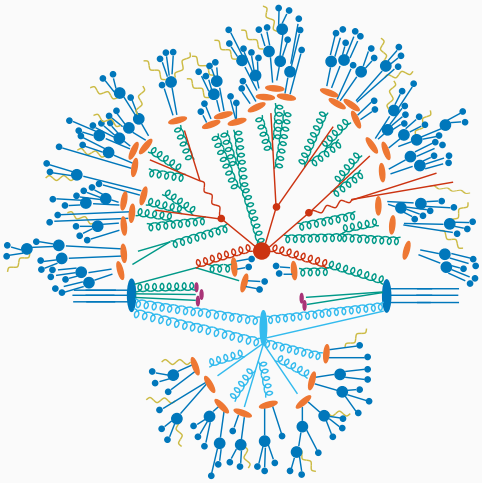

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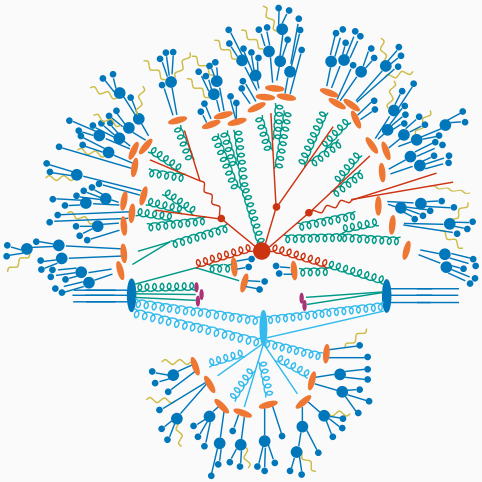
  - YFS soft-photon resummation
- Analysis and histograms primarily via RIVET



Features for lepton colliders

- YFS for lepton-lepton colliders Krauss, Price, Schönherr '22; Krauss, Price '25

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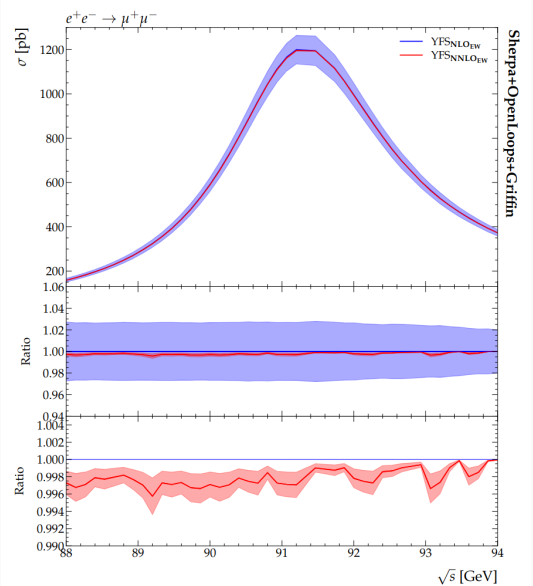
Order counting

Latest developments

YFS soft photon resummation

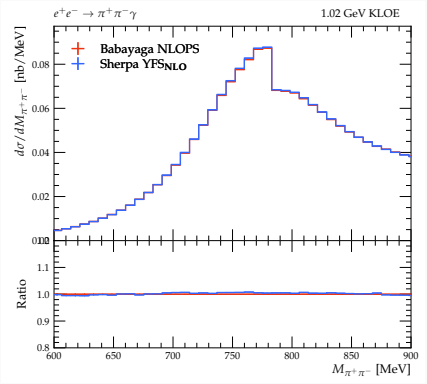
- Automated NLO matched to YFS in EEX framework
- NNLO for $e^+e^- \to \mu^+\mu^-$ for energy scan over Z resonance
- We find NNLO is very consistent with NLO
- Perturbative uncertainty band reduced



YFS for low energies

KLOE small-angle scenario

- SHERPA is NLO $\pi^+\pi^-\gamma$ matched to YFS
- BABAYAGA is NLO $\pi^+\pi^-\gamma$ matched to parton shower
- Agreement within 2% across $M_{\pi\pi}$ spectrum



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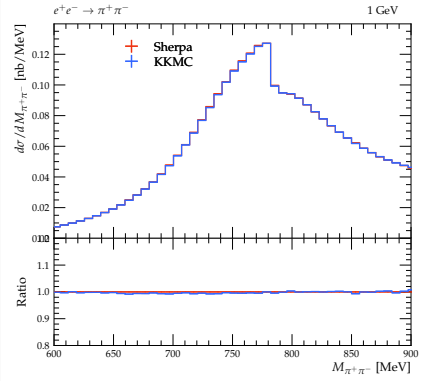
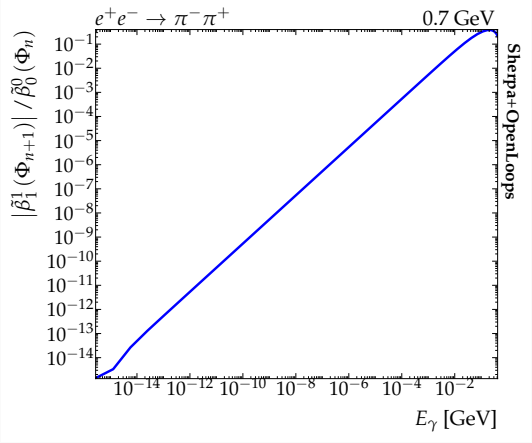
KLOE small-angle scenario

- Comparison at NLO $\pi^+\pi^-$ with KKMC CEEX gives 1% agreement

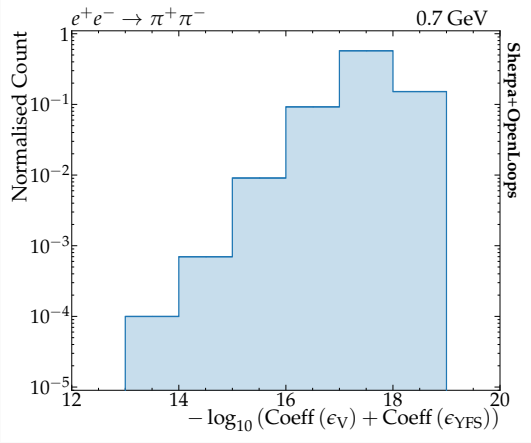
$\rightarrow$ different paradigms are crucial to estimate theoretical uncertainty beyond naïve MHOU



YFS as a subtraction scheme



Cancellation of divergences in real

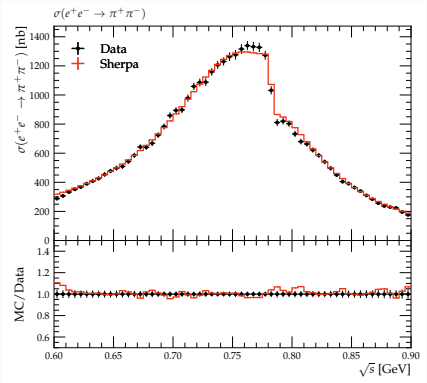


Cancellation of divergences in virtual

Same exercise for NNLO Krauss, Price '25

Comparison with data

- SHERPA YFS+NLO with pion FF
- HVP in Jegerlehner parametrisation
- Well-describes BESIII data on $\rho - \omega$ interference at the 5% level
- Improvements needed in matching order and pion treatment for percent-level agreement with more precise data



YFS+NLO vs BESIII

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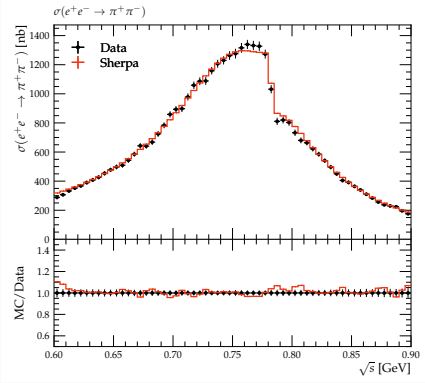
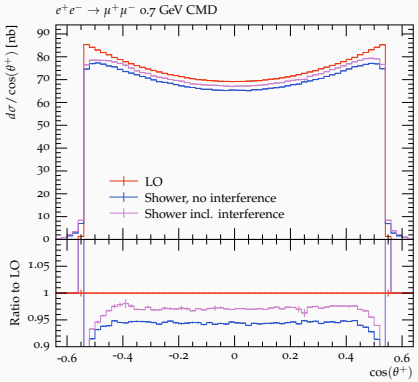


YFS+NLO vs BESIII

More analysis preservation in RIVET needed

QED parton shower

- Photon radiation (and optionally charged particle production) from all external legs
- QCD shower paradigm: evolution outwards from amplitude
- Allows for equal treatment of ISR, FSR and interference
- Separate ISR and FSR fully implemented and validated
- Radiation off pions in sQED approximation



Preliminary

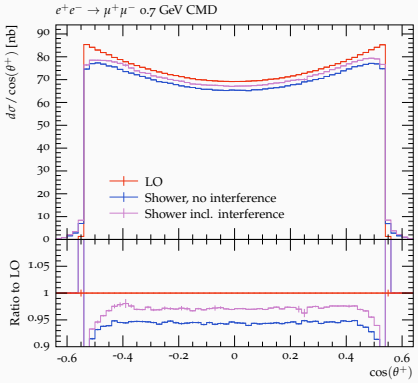
10x more stats for interference

Comment on initial-final interference

- We see that IF interference effects are very large for the standard LO shower
- But in SHERPA vs KKMC YFS, we see no such effect

→ effects are probably captured sufficiently at fixed order

- Dedicated study possible in the future with new CEEX → Jérémy's talk



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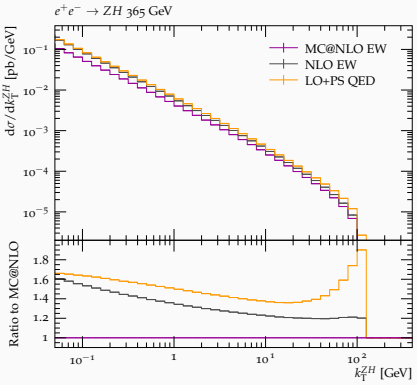
Automated NLO parton shower matching

- QED extension of MC@NLO method Frixione, Webber '02
- Cross section and IR-safe observables to $\mathcal{O}(\alpha)$, further radiative corrections in shower approximation
- Easily extendable to NLL lepton PDFs
- Application to low-energy in progress



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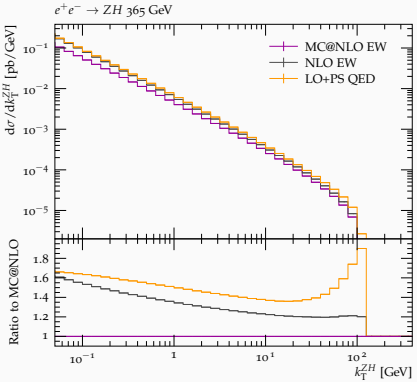

Flower, Schönherr '26

Limited to NLO, but for any number of legs

Work to extend to NNLO ongoing within QCD research

Conclusions

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- Application of YFS to MUonE Price '25
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Download and manual
sherpa-team.gitlab.io

Thanks for listening!